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Final Report

PHASE ONE STUDY

EVALUATION OF SOLID WASTE AS PHYSICAL AND CHEMICAL AMENDMENTS AND REVEGETATION OF COAL SURFACE MINE SPOILS

INT GRANT NO. 22
Montana State University
August 1976

Final Report

to

Forestry Sciences Laboratory
Intermountain Forest and Range Experiment Station
USDA Forest Service
Logan, Utah

on

PHASE ONE STUDY
EVALUATION OF SOLID WASTE AS PHYSICAL AND CHEMICAL AMENDMENTS AND REVEGETATION OF COAL SURFACE MINE SPOILS

INT GRANT NO. 22

by

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August 1976

TABLE OF CONTENTS

	Page
LIST OF TABLES	iii
LIST OF FIGURES	iv
I. INTRODUCTION	1
A. Statement of Problem	3
B. Project Objectives	5
C. Objectives--Phase One Study	6
D. Limitations and Alterations--Phase One	6
E. Objectives for Phase Two	7
F. Limitations--Phase Two	8
II. LITERATURE REVIEW	9
A. Benefits and Limitations--Land Applications of Sewage Sludge	9
B. Refuse as a Soil Conditions	17
C. Reclamation of Mine Spoils at Colstrip	22
D. Summary	25
III. ACCOMPLISHMENTS--PHASE ONE	27
A. Summary of Progress	27
B. Second Greenhouse Experiment	29
C. Lycimeters	37
D. Vacuum Collection System	39
E. Site Survey	41
F. Plowing	44
G. Atomic Absorber	46
H. Sample Preparation	49
I. Laboratory Columns	50
IV. CONCLUSIONS	51
V. ACKNOWLEDGMENTS	54
VI. REFERENCES	56
VII. APPENDIX	60
A. Purpose	61
B. Progress to April 15, 1976	61
C. Expected Accomplishments with Project Funds	69
D. Proposed Extension of Time	70
E. Available Funds	70
F. Tentative Budget July 1, 1976-June 30, 1977	71
G. Conclusions	73

LIST OF TABLES

Table		Page
1.	Typical values of nutrients and heavy metals in sludge	10
2.	Allowable heavy metal content of sludge for land application and saleable crops	13
3.	Heavy metals in pasture	14
4.	Characterization of solid waste	18
5.	Forage yields and zinc-chromium concentrations in corn crops	20
6.	Legend for soil-refuse-sludge mixtures	30
7.	Plants in second greenhouse experiment	36
8.	Chemical analysis of soils and amendments	65
9.	Plants in first greenhouse experiment	66

LIST OF FIGURES

Figure		Page
1.	Fertilized Topsoil. Second Greenhouse Experiment	31
2.	Unfertilized Refuse and Clay. Second Greenhouse Experiment	32
3.	Unfertilized Sludge and Clay. Second Greenhouse Experiment	33
4.	Unfertilized Mixtures of Sludge and Refuse. Second Greenhouse Experiment	34
5.	Unfertilized Topsoil. Second Greenhouse Experiment	35
6.	Overview of Second Greenhouse Experiment	35
7.	Lycimeter	40
8.	Vacuum Collector	42
9.	Experimental Plot on Old Permit Lands. Big Sky Mine, Colstrip	43
10.	Pulverized Municipal Refuse from City of Great Falls	45
11.	Refuse Piles up in Front of a Small Farm Disc	45
12.	After 4 Passes of Towner 8-Ton Disc. Foreground Refuse Was 6 Inches Deep. Background Refuse was 4 Inches Deep	47
13.	Growth at 40 Days in Topsoil	67
14.	Growth at 40 Days in Clay-Refuse-Sludge Mix (3SR)	67

I. INTRODUCTION

In past years, strip mining of coal has resulted in a wasteland of spoil banks. Among its mineral riches, Montana has vast reserves of coal, some of which were mined near the turn of the century. Old spoil banks, barren and desolate, are still to be found. Large scale strip mining by the Northern Pacific Railroad took place in the Colstrip area from the 1920's to the 1950's. In 1968, Montana Power Company began strip mining near Colstrip. Senate Bill 70, The Montana Open Cut or Strip Mine Land Reclamation Act, was passed in 1971, and lands mined under this act are called "old permit" lands. Essentially, such lands were graded into gently rolling terrain. Vegetation eventually establishes itself on such lands, and the process can be hastened by plowing and seeding the spoil material. Lands now mined are reclaimed under Title 50 R.C.M. 1947, The Montana Strip and Underground Reclamation Act which was passed in 1973 and is administered by the Department of State Lands. Such lands are called "new permit" lands. Essentially, the topsoil is selectively stripped and stockpiled, the underlying spoil is stockpiled, then (after the coal is removed) replaced, graded to suitable contours and covered with the topsoil. If the topsoil is thin or of poor quality, the best material in the area is used. Topsoil may include the upper eight foot horizon, but in the Colstrip area, the "unconsolidated mineral matter" at the surface is often very thin. The handling of the topsoil is said to be the most expensive part of the reclamation process. There does not appear to be a consensus of opinion on the actual cost, but various respondents have estimated costs for handling topsoil

to range between $400 and $700 or more per acre. The expense is caused by the number of handling steps: stripping, stockpiling, transporting back to the site, and spreading. Furthermore, topsoil on some of the lands in eastern Montana is too thin or too poor. A substitute for the topsoil would be beneficial even if it could be applied only to a fraction of the land area.

Disposal of municipal refuse is a serious problem in all of the towns and communities of southcentral Montana, an area consisting of the following 11 counties: Judith Basin, Fergus, Petroleum, Wheatland, Golden Valley, Musselshell, Sweetgrass, Stillwater, Yellowstone, Carbon, and Big Horn. Gildroy (1974) emphasized that property for sanitary landfill is difficult to purchase or obtain in some areas, most of the communities lack adequate equipment for the collection and disposal of solid wastes, and existing conditions and methods are no longer adequate because they present fire hazards, safety hazards, potential for water pollution, inconvenience, and nuisance from smoke, odor, and unsightliness. Economical disposal of municipal refuse in scattered, individual sanitary landfills is questionable because of the low volumes of solid wastes generated in many communities. A centralized collection and disposal system in which the recovery of valuable materials could be economically practiced and in which some beneficial use could be made of the remainder of the material is highly desirable. The firm of Henningson, Durham & Richardson, with a branch office in Helena, is engaged in a 1-1/2 year investigation entitled "Solid Waste Management and Resource Study for the State of Montana." That study, begun July 1975, is about three-quarters completed and has resulted in several reports (1976a, 1976b, 1976c). The thrust of those reports is toward the use of the combustible fraction of municipal refuse for use as fuel at steam or electricity generating plants. However desirable that solution may be, there is still a problem of the disposal of the incombustible

fractions (ash and rejects such as dirt and glass) which occupies approximately 5 percent of the volume (25 percent by weight) of the processed portion.

With the implementation of PL 92-500, (Federal Water Pollution Control Act Amendments of 1972), all municipalities discharging sewage into surface waters must have secondary treatment by July 1, 1977. Several municipal sewage treatment plants (including the City of Billings Wastewater Treatment Plant), will soon be in operation. It is characteristic of secondary sewage treatment plants that large volumes of stabilized sludge are produced. The disposal of that sludge has become an extremely serious problem in centers of concentrated population such as Chicago and New York. It is also a problem in other communities, where the usual method of disposal is in a sanitary landfill. Although sludge is not a fertilizer, it is nevertheless rich in nutrients and is an excellent soil conditioner. There are a great many examples of its beneficial use as a soil amendment.

A. Statement of Problem

As a result of the study by Gildroy (1974), the best disposal plan developed involved pooling all collection and disposal under a centralized management. The most economical plan would be to gather solid wastes from all communities in the 11 counties and transport them to a single facility for processing. The combined tonnage of the collected waste would make it feasible to separate salvageable materials, store them for marketing, and pulverize the balance of the material. The pulverized waste can be disposed of in four ways: (1) burned as fuel, (2) placed in a sanitary landfill, (3) used as a soil conditioner close to the centralized facility, and (4) transported to the Colstrip area where the need for soil conditioner in mine spoils is greatest. Economics

would control the location of the centralized processing facility in Billings or at Colstrip.

Although it would be highly desirable to combine the problems of reclamation of strip-mined areas with the beneficial use both of municipal refuse and sewage treatment plant sludge, there are serious problems--technological, economical, and political. The technological problems include (but are not confined to): processing the refuse and the sludge, holding it (when conditions are inappropriate for land application), transporting, spreading, and incorporating it into the soil, possible release of heavy metals or other toxic substances to migrate into ground water or to be adsorbed by plants (which might adversely affect meat quality of grazing livestock), ultimate degradation of slowly-decaying materials, unsightliness, and biological health hazards. These problems must be weighed against benefits which include (but also are not limited to): enrichment of the soil with nutrients, increased infiltration capacity and reduction of erosion due to wind or water.

The economic problem is more complex than a simple analysis of the costs to process, transport, spread, and incorporate a waste material. Not only should all alternatives and ancillary costs be considered, but the ultimate worth of the land, the availability of topsoil for reclamation, and the cost-sharing of communities which benefit by central collection should be considered. Furthermore, there are the intangible benefits of converting a waste into an asset.

The political problems may prove to be the most difficult of all. In addition to the problems of securing cooperation between municipalities, counties, state and federal legislative and regulatory bodies, there is the contention of many groups with different viewpoints and interests--farmers,

ranchers, miners, environmental groups, and others. Furthermore, decisions have long-range consequences and should not be lightly reached.

The difficulties of solving these technical, economical, and political problems are compounded by the diversity inherent in all aspects of these problems. That which is applicable in one area, or for one soil, or for one kind of waste, may be inappropriate for another. Thus, solutions are not directly transferable from one project to another. So although extensive studies are underway at a number of locations throughout the United States, the variabilities of locations, wastes, soils, geology, weather, and other factors make it necessary to evaluate each project for the specific project site.

B. Project Objectives

The general objectives of the entire project are to develop techniques for and to evaluate the effects of using municipal refuse and wastewater treatment plant sludge as physical and chemical amendments in the revegetation of coal surface-mine spoils in eastern Montana.

The specific objectives of the entire project are:

1. Physical handling and economics of the collection, transportation, processing, unloading and storage, pulverizing and storage, application to land, and resource separation and sales.

2. Chemical analysis of solid waste constituents including C:N:P ratios and selected heavy metals.

3. Effects of pulverized solid wastes on water retention and effect on water movement and balance, erosion of soil by wind and rain, crop yield, addition of nutrients, and chemical composition of crop and crop quality, and migration of salts and heavy metals.

4. The impact of proper utilization of pulverized municipal refuse and municipal sewage treatment plant sludge.

C. Objectives--Phase One Study

The specific objectives of the Phase One study dating from June 16, 1975 to August 30, 1976 are as follows.

1. Limited chemical analyses of solid wastes and municipal sludges and the need for augmentation with commercial fertilizer.

2. Establish reclamation plots and apply approximately 50 tons of pulverized solid wastes from Great Falls on a selected site near Colstrip with and without the addition of sludge and fertilizer additives, and plant crops for comparison with crops on shale and topsoil (to act as control). Correlate and coordinate with ongoing research on reclamation of strip-mined lands in the Colstrip area.

3. Determine the need and priorities for in-depth study in Phase Two (1976 to 1977) to satisfy overall project objectives.

4. Physical handling and economics relating to procedure or methods and equipment.

D. Limitations and Alterations--Phase One

As the work progressed, it became apparent that a restructuring of priorities in Phase One was required. The need to analyze heavy metals and to estimate their migration was stated in the original proposal. But the subsequent, vehement resistance by government agencies to the use of refuse and sludge (on the basis of heavy metal concentrations) led to the realization that the fate of the heavy metals must be determined. Instead of a few measurements to determine concentration of heavy metals, a careful study to determine extent and rate of movement was needed, and this required: (a) a battery of lycimeters (not contemplated previously) to sample percolate, (b) an elaborate soil sampling program to measure, if possible, migration rates,

(c) supporting laboratory tests with soil columns, (d) a very large increase in the number of heavy metal determinations to be made which requires improved sampling techniques and a breakthrough in instrumental analysis.

The change of priorities described has shifted some of the specific objectives from Phase One to Phase Two and it has added considerable effort (not mentioned in the preceding objectives) to Phase One. Specific Objective No. 2 was altered as follows: (a) two extensive laboratory (greenhouse) experiments were made with soils, refuse and mixtures complete with laboratory chemical analyses, (b) suitable lycimeters and vacuum collectors were developed and built, (c) modifications of an atomic absorber (which should make chemical analyses much easier and quicker) are underway, and (d) the placement of wastes in the field (and installation of lycimeters) has been relegated to Phase Two.

The limitations of funds, and consequently manpower and time, have meant from the outset that the project must be exploratory in nature.

Specific Objective No. 4 should be regarded as a continual development. Some parts have been accomplished, but this objective can be completed only at the end of the entire project period.

E. Objectives for Phase Two

The objectives in Phase Two of this study (September 1, 1976 to August 31, 1977) are: to seed the experimental plots near Colstrip, to study crop production, and to trace movement of selected heavy metals. More specifically, the objectives for Phase Two are:

1. Install the lycimeters (which have been manufacturered) and install the vacuum collection system.

2. Transport approximately 100 tons of pulverized municipal refuse and 80 tons of City of Great Falls sewage treatment plant sludge from Great Falls

to the experimental site at Big Sky Mine of Peabody Coal Company (near Colstrip) and incorporate these wastes into the upper 16 inches of soil.

3. The Animal and Range Science group (directed by Richard Hodder) is to seed the area with a selected mixture of grasses. The target date for seeding is Autumn 1976. This group is to monitor the growth and make the chemical analyses necessary for evaluation of the crop.

4. Monitor the underground lycimeters.

5. Obtain soil samples under the waste for the various different experimental plots.

6. Continue development work with the remodeled Varian atomic absorber and analyze the lycimeter samples and the soil samples.

7. Attempt to determine a rationale for the required number of samples and frequency of sampling to enable the heavy metals to be traced.

F. Limitations--Phase Two

Solid waste is extremely variable in character, both from sample to sample as well as from season to season, so it can be expected that many samples may have to be taken to arrive at an "average" or typical value. And as soils must be sampled at several depths to trace the movement of heavy metals, a great many samples may be required. Thus, the time and cost of chemical analyses may be very great. In order to reduce the costs insofar as possible, the use of a Woodriff furnace on an atomic absorber is being explored, but this work is new and it has not been reported in the literature. While the prognosis for success is good, the construction and testing of new instrumentation is always accompanied by difficulties and delays. On the other hand, to make the chemical analyses in the standard manner is costly as it ranges between $3 and $5 per sample. The most serious limitation for Phase Two is the probable but unknown success of the system proposed for sampling and analyzing for heavy metals.

II. LITERATURE REVIEW

The literature dealing specifically with the area of the study is limited --namely, the evaluation of sewage sludge and municipal refuse as soil amendments for coal mine spoils in relation to the benefits as a fertilizer and its limitations due to the toxicity of heavy metals. However, an extensive literature exists in the separate areas of: (a) benefits and limitations of the land application of sewage sludge and (b) benefits of refuse as a soil conditioner. The following is a literature review which assembles noteworthy material in the above areas as background material for the study. In addition, the studies in reclamation of the Colstrip area are also reviewed.

A. Benefits and Limitations - Land Application of Sewage Sludge

The physical, chemical and biological properties of sludge produced by various treatment processes were evaluated by Dean and Smith (1973). They indicated that sludge contains the major plant nutrients, nitrogen, phosphorus, and potassium at levels about one-fifth of those found in chemical fertilizers. The nitrogen from sludge is released slowly which makes it a desirable fertilizer for lawns and greens that require slow growth. Typical values of nutrients and heavy metals found in sludge are indicated in Table 1. The values for heavy metals were quoted from an EPA report (under preparation) which assembled the data from a source of 100 literature references. The values quoted under atomic absorption were from 80 samples of sludge analyzed from different treatment plants. The limiting factor in regard to nutrients was

nitrogen which tended to percolate into groundwaters as nitrates. Phosphate was strongly bound to soils and pollution due to excess phosphate or potassium was insignificant.

TABLE 1

TYPICAL VALUES OF NUTRIENTS AND HEAVY METALS IN SLUDGE
Source: Dean and Smith (1973)

Nutrient	Range of values as percent dry solids	Element	Literature		Atomic Absorption
			Geometric Mean (ppm)	Spread*	Geometric Mean (ppm)
Total N	3.5 - 6.4	Cd	61	5.89	93
Organic N	2.0 - 4.5	Cu	906	2.66	1840
P	0.8 - 3.9	Hg	14.5	5.24	3.2
P_2O_5	1.8 - 8.7	Ni	223	4.54	733
K	0.2 - 0.7	Pb	404	4.13	2400
K_2O	0.24 - 0.84	Zn	2420	2.78	6380

* Spread is antilog of standard deviation of log normal distribution

The arithmetic mean of the heavy metals concentrations in Table 1 was twice the median value. Stevenson (1972) showed that organic matter in sludge caused chelation of the metals resulting in a decrease of the quantity of metal available to plants. Smith and Bradshaw (1972) showed that certain varieties of plants have an inherent resistance to toxic metals in the form of a cytological barrier.

Lindsay (1973) indicated that zinc, cadmium, copper and nickel were held in small quantities as exchangeable ions consequent to precipitation reactions which lowered their level of solubility. The precipitation reactions probably involved substitution in crystalline minerals and amorphous precipitates as well as formation of silicate compounds. Studies indicated that activities of these

metal ions decreased with an increase of pH. For zinc and copper, nearly a 100-fold decrease in activity occurred for each unit of increase in pH. Long-term effects and possible formation of soluble complexes and chelation need to be studied. Lindsey also indicated that mercury formed insoluble compounds and that soils had a very large capacity to immobilize lead. Thus, soil appeared to be an excellent sink for these two metals.

Melstead (1973) suggested tolerance levels of heavy metals on the basis of: (a) toxic levels for animals, (b) plant levels at which applicable transfer of the element from the vegetative portion to the grain occurs, and (c) the level known to be toxic to the plant itself. The suggested tolerance values in ppm for some of the elements in various crops were: cadmium - 3, copper - 150, mercury - 0.04, nickel - 3, lead - 10, and zinc - 300. Values were also suggested for several other elements. The above values applied to whole grasses harvested at early hay cutting stage. Since most heavy metals are immobile in the soil, Melstead indicated that the depth of plowing and the type of crop would have an effect on the quantity of metals transferred to the grasses. For example, grasses harvested early would have higher concentrations than legumes.

Chaney (1973) reported on the crop and food chain effects of toxic elements in sludges. Factors controlling metal toxicity to plants were summarized as: (a) the amount of toxic metals present, (b) the Zn equivalent factor, (c) pH, (d) organic content, (e) phosphate content, (f) cation exchange capacity, (f) time, and (h) plant species, and all of these factors controlled the amount of metals available for translocation by the roots. Zinc, copper and nickel were clearly toxic to plants and generally copper was twice as toxic and nickel eight times as toxic as zinc. Chumbley's (1971) Zn Equivalent Factor [Zn equivalent in ppm = 1 x ppm Zn + 2 x ppm Cu + 9 x ppm Ni] took into account the variability in toxicity. For agricultural soils with pH maintained at 6.5 and

above, Chumbley suggested that the Zn equivalent added by sludge application should be less than 250 in any 30-year period. The pH of the amended soil was an important variable. As the pH decreased below 6.5, the toxic metals became increasingly available to plants. The organic content of the amended soil chelated the toxic metals and made them less available to plants. It was especially important in binding the copper and nickel. Mann and Barnes (1956) indicated that as the organic matter decomposed, its protective effect was lost and the soil could become toxic. The phosphate content of the amended soil reduced zinc availability, but enhanced iron deficiency and cholorosis caused by excess copper and zinc. The cation exchange capacity of the soil was important in binding all potential toxic cations. Some toxic metals reverted with time to forms which were less available to plants. This was indicated by DTPA-extractable studies by Follett and Lindsey (1971), especially for zinc. Plant species had varying tolerances to toxicities. Chaney also mentioned that the root was the metal-sensitive organ of plants. The elements that were a potential hazard to the food chain by plant accumulation were cadmium, copper, and zinc. Zinc appeared to compete with cadmium at sites of uptake in plants and animals. By maintaining the cadmium content at less than 0.5 percent of the zinc concentration, a zinc excess at 500 ppm in leaves would injure the crop before concentrations of zinc or cadmium reached health hazard levels. This was the basis of subsequent guidelines suggested by EPA (1974). Copper caused severe plant injury before the content was high enough to be toxic to animals.

Chaney (1973) indicated that, in general, the benefits of sludge application are the supply of organic matter, nitrogen, phosphate, zinc, and copper. The risks were toxic metals in excessive concentrations. For agricultural lands with continuous general farming, he suggested that the sludge could contain heavy metals to concentrations indicated in Table 2. The toxic metal

additions to soil should be such that they do not exceed the zinc equivalent level equal to five percent of the cation exchange capacity of the unamended soil at a pH equal to or greater than 6.5. The criteria were not deemed to apply for sites not used to grow crops for sale.

TABLE 2

ALLOWABLE METAL CONTENT OF SLUDGE FOR LAND APPLICATION AND SALEABLE CROPS
Source: Chaney (1973)

Element	Zn	Cu	Ni	Cd	B	Pb	Hg
Maximum concentration, ppm	2000	800	100	0.5% to 1% of Zn	100	1000	15

Spyridakis and Welch (1976) indicated that the insoluble hydrous oxides of manganese and iron, alone or in combination with organic matter, provided one of the principal controls of the micronutrients: nickel, copper, cobalt, and zinc in soils. The heavy metals are occluded on the hydrous oxide coatings, and pH and Eh are the significant variables responsible for retention of the heavy metals in the top few centimeters of soil.

Hyde (1976) reported on the use of wastewater sludge for agricultural soil enrichment in the East Bay Municipal Utility District. The study was conducted in low-productivity grazing lands deficient in nutrients and organic matter; additionally, the soil had: (a) a fine texture and a permeability which limited the deep percolation of nutrients, (b) a high exchange capacity for adsorbing cations, and (c) a high potential for phosphate fixation because of its alkaline character (pH 8.3) due to the presence of lime. Sludge applied at rates of 4 to 32 dry tons/acre significantly improved the productivity of the land. Field corn production increased by 20 percent and pasture forage by 300 to 400 percent. Micrbiological studies indicated survival of pathogenic

organisms after 7 months. Hyde stated that the effect of heavy metals on the soil-plant-water ecosystem and possible concentrations in the food chain was the significant obstacle to land application of sludges. Table 3 summarizes the results of Hyde's study and compares the results with phytotoxicity limits established by Leeper (1972) for the Army Corps of Engineers. Long-term environmental effects for heavy metal accumulations in soils were not determinable. However, possible approaches suggested were to use the EPA criteria (1974) or the Water Quality Criteria (1972) for irrigation and determine the allowable accumulations in soil over a 20-year period.

TABLE 3

HEAVY METALS IN PASTURE
Source: Hyde (1976)

Element	Concentrations (DTPA extractable), ppm			
	Original soil	Sludge treated soil	Forage	Phytotoxic levels[a]
Dryland pasture				
Cd	0.12	0.15	0.40	Unknown
Cu	1.80	7.9	11.0	30
Ni	1.20	3.3	5.0	25
Zn	3.60	11.5	74.4	500
Zn:Cd	30.0	76.7	186.0	100
Irrigated pasture				
Cd	0.06	0.16	0.22	Unknown
Cu	1.86	9.3	7.3	30
Ni	1.26	4.1	5.6	25
Zn	0.90	13.9	58.8	500
Zn:Cd	15.0	86.9	267.3	100

a. Leeper (1972)

Based on the studies of Leeper (1972) and Chaney (1973), the Environmental Protection Agency suggested (1974) the following equation for limiting the total amount of sludge which may be applied to agricultural lands.

$$\text{Total Sludge (dry wt. tons/acre)} = \frac{\text{CEC} \times 32{,}600}{(\text{ppm Zn}) + 2(\text{ppm Cu}) + 4(\text{ppm Ni}) - 30}$$

where CEC = cation exchange capacity of unamended soil in meq/100 g

ppm = concentration of metals in mg/kg dry weight of sludge

The proposed EPA guidelines (1974) would also limit the cadmium content of applied sludge to less than 10 ppm and the Zn/Cd ratio to 100 or more.

The Metropolitan Sanitary District of Greater Chicago and the University of Illinois have conducted studies since 1968 to determine how chemical changes in sludge would affect the nutrition and toxic metal concentrations of soybean and corn. These studies were reported by Hinesley et al (1974), Zenz et al (1975) and Lue-Hing et al (1975). These studies showed that during the seven-year study, no phytotoxic conditions resulted from heavy metal translocation in a silty soil receiving cumulatively up to 164 tons/acre of sludge for corn, and 114 tons/acre for soybeans. Metal levels in the corn grains were not increased by increasing years of sludge application but only by the sludge applied in any growing year. The cadmium content of the grain did not exceed 1.1 ppm through 1973 after reaching a level of 1.0 ppm in 1970. The concentration of Zn and Cd in corn leaf, grain and mature plant residues were increased in any year by greater application of sludge (Cd, 1972: 1.1 ppm, 9.0 ppm, 18.8 ppm and 22.2 ppm), but metal concentrations were not elevated by increasing years of application (Cd, 1970-1973: 5.3 ppm, 7.5 ppm, 18.8 ppm, 6.9 ppm). Even decreases in concentration have occurred with increasing years. These authors argue that current EPA guidelines are not supported by available

scientific data and that the proposals would eliminate land utilization of nearly 90 percent of the sludges produced in the states of Illinois, Wisconsin, and Indiana. They concluded that, if the sewage sludge is applied to soils at an annual rate consistent with the yearly nitrogen requirements of the crop, and if the application rate is also based on accumulative phosphorus levels, then heavy metal problems in the food chain and plant phototoxicity will not occur.

Kirkham (1975) in a study of corn grown on a soil treated with municipal sludge at 12.6 tons/acre/year for 35 years at Dayton, Ohio found that the surface 12 inches of soil accumulated heavy metals by the following factors: Cd - 35, Cu - 16.5, Ni - 2.0, and Zn - 13. However, these elements did not accumulate in the grain of corn plants. Concentrations of cadmium and copper were higher than normal in the leaves. The concentrations of all elements decreased by factors of 2 to 10 with soil depth increases from 2 to 3 feet. The acid-extractable values of the metals were of the order of 0.5 to 10 ppm whereas the total available concentrations ranged from 20 to 100 ppm. The loadings of sludge at this site were 40 to 50 times higher for copper, nickel, lead and zinc and nearly 100 times higher for cadmium than those recommended by Leeper (1972), Chaney (1973) and the EPA (1974). However, the uptake into corn grain was small.

Two recent studies by Bingham et al (1976) and Touchton et al (1973) have indicated that coastal bermudagrass had the highest tolerance to high concentrations of heavy metals in soils. Bingham's study showed that a 25 percent decrease in yield was indicated for tissue cadmium concentrations exceeding 9, 17, 24, 37, and 43 µg/g for sudangrass, white clover, alfalfa, fescue, and bermudagrass, respectively. The corresponding substrate cadmium concentrations

were 15, 40, 30, and 145 mg/g soil. These data indicate the considerable tolerance of bermudagrass to high cadmium levels in soils.

Walker (1975) presented a review publication which discussed management aspects of land application of sewage sludges and the complications due to the psychological objections of the public. Walker also discussed sludge handling and incorporation techniques, management for reduction of detrimental effects such as heavy metals and enhancement of beneficial aspects such as fertilizer value. Guidelines for sludge use based on fertilizer requirements, land use, and monitoring requirements were suggested.

B. Refuse as a Soil Conditioner

Literature about the management of solid waste tends to deal largely with operational aspects, the evaluation of alternatives of composting, landfilling, and incineration. The utilization of solid waste has been for reclaiming areas by filling rather than by using it as a soil amendment. Thus, studies in the area of refuse as a soil conditioner are extremely limited. There is, however, a growing body of knowledge in the area of analyzing and evaluating leachates from landfill sites and their potential for polluting ground and surface waters.

The most relevant study for characterizing the refuse from Great Falls, Montana was by Henningson, Durham & Richardson (1976a) for the State of Montana. The waste generated was determined to be 5.63 lbs per person per day (wet weight) consisting of the composition indicated in Table 4. The table also shows the seasonally adjusted values for four major cities in Montana (Missoula, Butte, Billings, and Great Falls), the nationally published data of the Environmental Proection Agency (EPA), and the National Center for Resource Recovery (NCRR).

Rovers and Farquhar (1973) studied the infiltration and leachate characteristics of landfills in laboratory columns and under field conditions in

Ontario, Canada over a period of 350 days. Maximum leachate production occured during the spring thaw. The characteristics of the waste and rainfall conditions are not very different from those in Montana. Rovers and Farquhar found that moisture absorption prior to leachate production ranged from 1.2 in./ft to 1.7 in./ft of compacted refuse. The leachate was of considerable strength; typical COD was 40,000 mg/l and ammonia nitrogen was typically 600 mg/l. The concentrations of some of the heavy metals in the leachate from 10 ft deep refuse were: Ni - 0.4 to 0.9 mg/l, Cu - 0.0 to 0.45 mg/l, Cd - 0.0 to 0.7 mg/l, and Zn - 14.0 to 20.0 mg/l.

TABLE 4

CHARACTERIZATION OF SOLID WASTE
Source: Henningson, Durham & Richardson (1976a)

Waste Component	Wet weight, %			
	Great Falls	Montana Adjusted	EPA	NCRR
1. Paper	35.1	38.2	37.8	42.7
2. Plastic	4.2	5.8	3.8	1.7
3. Yard	28.0	11.7	14.6	12.5
4. Food	13.6	19.3	14.2	14.6
5. Glass	6.5	8.7	10.0	10.3
6. Metals	8.4	10.6	10.1	9.5
7. Other (cloth, wood, etc.)	4.2	5.7	9.5	8.7
Total	100.0	100.0	100.0	100.0

Reinhardt and Ham (1973a, 1973b) studied the characteristics of leachate from covered unprocessed refuse and milled refuse (2 in. to 0.1 in.) with and without soil cover in several cells 5 to 6 ft deep, in Madison, Wisconsin. The milled refuse cells produced more leachate contaminants during the initial stages of decomposition but less during the later stages of decomposition when

compared with unprocessed refuse cells. The unprocessed covered cells produced COD's from 4000 to 12,000 mg/l over a two-year period. Water budget analysis showed that 68 percent of incident precipitation on covered refuse in a landfill evaporates and the balance (32 percent) is divided equally between runoff and infiltration. The above results were part of an extensive 5-year study on the milling of refuse.

Mortvedt and Giordano (1975), in one of the very few studies which evaluated municipal solid wastes and sludge on plant growth and uptake of heavy metals, showed that zinc and chromium contained in municipal wastes applied at high rates were not toxic to corn even after 18 months in the soil. Two greenhouse pot experiments were conducted in which 3 successive corn crops were grown with the application of two different sludges and a compost (prepared from garbage and 20 percent sludge). The soil was limed to a pH of 5.5, and fertilizers were added to all pots at a rate of 600 mg of N as ammonium nitrate, 300 mg of P as superphosphate, 200 mg of K as potassium sulphate and 20 mg of Mn as manganese sulphate to each 3 kg of soil in the pot. None of the crops was greatly affected in terms of yield even though the applied zinc and chromium concentrations were as high as 1400 ppm and 1360 ppm, respectively. The concentrations of zinc and chromium in the plant tissue were 508 ppm and 1.4 ppm in the first crop. Subsequent crops showed decreases in zinc (90 to 80 ppm per crop) but an increase in chromium (0.2 to 0.8 ppm per crop) concentrations. The results indicated that crop recovery of zinc from these wastes was less than 5 percent. Corn forage yields were increased by compost but were unaffected by sludge applications. Concentrations of zinc in tissue increased with the zinc application rate as well as zinc content, but chromium levels did not change significantly by increases of concentration in the soil from 3 ppm to 1360 ppm.

In contrast, the second experiment with zinc and chromium added as inorganic salts at similar concentrations (1400 ppm for zinc and 320 ppm for chromium) produced significant decrease in yield when the zinc applied was greater than 240 ppm or when the chromium levels were higher than 80 ppm. Heavy concentrations occurred in the plant tissue, and in the first crop of the second experiment the concentration of zinc was 10,178 ppm, an eight-fold increase. Since the soil in both experiments was limed to similar pH levels, it was concluded that plant uptake of these heavy metals in organic wastes was not entirely due to liming. The levels of acid extractable (0.5 NHCl) zinc and chromium in the soil increased after each crop and nearly 60 percent recovery of zinc and chromium was possible at the highest waste application rate. The DTPA extractable levels were not as high as the acid extractable values. Table 5 summarizes some of the results of Mortvedt and Giordano.

TABLE 5

FORAGE YIELDS AND ZINC-CHROMIUM CONCENTRATIONS IN CORN CROPS
Source: Mortvedt and Giordano (1975)

Treatment	Applied Rate-ppm		Crop yield g/pot			Zn in crop tissue-ppm			Cr in crop tissue-ppm		
	Zn	Cr	1	2	3	1	2	3	1	2	3
1st Experiment											
Control	0	0	31	48	30	14	18	16	1.3	2.1	2.0
Sludge	70	68	33	50	34	196	121	163	1.2	1.7	2.3
	1400	1360	30	50	31	508	428	340	1.4	1.5	2.0
Sludge B	210	50	19	51	36	313	153	186	1.4	1.4	0.6
Compost	120	50	37	46	40	92	58	56	2.0	1.2	0.7
2nd Experiment											
$ZnSO_4$	60	--	30	45		1640	242		1.1	2.0	
	240	--	17	38		3067	892		2.1	2.3	
	1400	--	1	0		10,178	--		3.5	--	
$Na_2Cr_2O_7$	--	20	27	50		14	16		2.3	1.9	
	--	80	4	55		35	15		5.0	2.2	
	--	320	1	6		19	28		16.1	9.3	

In a follow-up study, Giordano et al (1975) investigated the crop uptake of several heavy metals contained in garbage compost and sewage sludge applied at relatively high rates in field trials. The treatments studied were application of: (a) compost (25.2, 50.4, and 110.8 tons/acre), (b) sludge (22.5, 45, and 90 tons/acre), and (c) zinc sulfate incorporated into the soil to provide zinc concentrations of 90, 180 and 360 ppm in the soil. The same treatments were reapplied to half of each plot in the following year. The effect of the various treatments were studied in terms of the yield and heavy metal concentrations in sweet corn and bush beans. Prior to planting, nitrogen and phosphorus fertilizers were added.

The results indicated that dry forage yields for compost and sludge were significantly greater than that of the plots treated with zinc sulfate. Although no toxicity was noted even with zinc sulfate concentrations of 360 ppm, the concentrations of Zn in the corn forage was 2 to 3 times greater with compost and sludge, and 5 to 10 times higher with zinc sulfate when compared with the control plot. Although soil extraction with 0.5 N HCl did not indicate a difference in Zn solubility between compost and sludge, plant concentrations of zinc were always higher with sludge. There was no correlation between plant uptake and soil extraction of the following heavy metals: lead, nickel, chromium, and zinc, but cadmium correlated well. Repeated application of the municipal wastes did not result in proportionally higher concentrations of heavy metals in plants. However, the potential for toxicity with high rates of application did exist.

Mays et al (1973) studied the field application of compost over a two-year period. They found that soil pH, organic matter, exchangeable cations of phosphorus, calcium, and magnesium increased with compost application. The acid (0.1 N HCl) extractable zinc in soil also increased. Their results of soil

and plant analyses indicated that multiple applications of heavy rates of compost could lead to potentially toxic accumulations of zinc. They obtained increased yields of bermudagrass, forage sorghum and corn with increasing compost applications up to 36 tons/acre for bermudagrass, 64.5 tons/acre for sorghum, and 50.5 tons/acre for corn. They also found a significant improvement in the soil texture and its moisture holding capacity due to applications of compost.

Purves and Mackenzie (1973) detected increased levels of copper, zinc, and boron in several vegetable crops as a consequence of compost application. When compost was applied at a rate of 45 tons/acre, severe phytotoxicity occurred in kidney bean plants due to boron accumulations.

Caffrey and Ham (1974) reported on the uncovered landfilling of coarsely shredded solid waste in Germany and Sweden. These landfills minimized leachate production until a relatively stable product was obtained from physical and biological degradation of the solid waste.

C. Reclamation of Mine Spoils at Colstrip

The interaction between energy and environment, the simultaneous need for exploitation and preservation, has resulted in considerable studies in the Colstrip region. A symposium on the Fort Union Coal Field which also includes the Colstrip region, sponsored by the Montana Academy of Sciences, assembled a considerable body of knowledge in a 5-volume publication of the proceedings.

Meyn et al (1975) in a paper presented at this symposium discussed the short and long term fertilizer requirements at Colstrip. The study area was characterized as: (a) soils - fine loamy and loamy skeletal lithic Haploboroll having fair productivity and poor stability, (b) climate - average annual

extreme temperatures range from 15°F to 90°F, with an average annual precipitation of 15 inches, almost 50 percent of which occurs as rain during the months April to July, (c) vegetation - consists of mixed prairie, grasslands, pine woodlands type with cool season bunch grasses (e.g., bluebunch wheatgrass) predominant. Examination of 20 to 30 year old mine spoils indicated the need for fertilizer amendments. The early fertilizer studies indicated that 75 to 100 lbs N and 50 lbs P_2O_5 per acre were adequate for first year plant requirements for wheat. Background potassium levels were of the order of 200 lbs per acre-ft and were deemed adequate. Spoil material at the Western Energy Company mine at Colstrip had the following properties over the entire depth of 4 feet studied: (a) Sodium - 0.13 meq/100 g, (b) pH - 8.2 to 8.4, (c) Organic matter - 0.15 percent, (d) Cation exchange capacity - 28 to 33 meq/100 g. The long-term fertilizer requirements for reclaiming spoils to rangeland is being studied.

Hodder et al (1970) have provided evidence that fertilizer applications have no significant effect on the density of first year plant production of seeded perennial grasses but were required to produce a vigorous and fast-developing cover for stabilization. The study indicated that a significant improvement in grass yield could be obtained by creating precipitation traps with an undulating surface on flattened ridgetops. Overburden profile analyses indicated that soil texture affecting percolation and tilth were of more significance than high mineral content or presence of toxic elements in the Western Energy Company mine at Colstrip. Chemical analyses of the soils did not indicate significant differences in surface, subsoil, or raw spoils. The pH values ranged from 8.4 to 8.6, organic content was at low levels (0.15 to 1.55 percent), and phosphorus and potassium levels were also low (8 to 80 ppm). The results on manipulating the surface of spoils to improve

infiltration and limit runoff have been further explored and confirmed by Sindelar et al (1973).

Hodder et al (1974) also reported on a continuing reclamation study at the Peabody Coal Mine in Colstrip. They presented data on the permeability of soils and a variety of chemical and physical characteristics including: pH, phosphorus, potassium, sodium, calcium, magnesium, conductivity, and particle size distribution. Most of the brown sand between the Rosebud and McKay croplines had adequate properties for use as a surface material for spoils. The Rosebud smut layer was impermeable and appeared to be unsuitable for plant growth, but the gray shale portion was an excellent plant growth medium provided its texture could be improved for permeability. All soils required amendments to provide plant nutrients. Data on groundwater characteristics and growth of several species of legumes to improve soil fertility by nitrogen fixation were also provided. They recommended three species of alfalfa, yellow sweet clover, and sainfoin as the most suitable.

In a continuing study, Richardson et al (1975) reported on rehabilitation at the Decker Coal Mine in Eastern Montana. The results indicated that mixtures of native and introduced grasses provide the greatest yields, and second year production (2065 lbs/acre) was substantially better than that of the first year (391 lbs/acre). The wheat grasses were the dominant species. Fall planting was superior to spring planting and mulching improved root as well as shoot production.

The concentrations of sulfur and 14 selected trace elements were determined by Chadwick et al (1975) on the Rosebud and McKay coal seams. Trace elements were analyzed using a constant temperature furnace atomic absorption spectrochemical technique designed by Woodriff (1968a, 1968b, 1972, 1973, 1974) at Montana State University. The ranges of the concentrations of some of the

trace elements in coal were: Cadmium - 1.5 to 0.02 ppm, Nickel - 163.5 to 1.6 ppm, Zinc - 361.0 to 1.7, Copper - 40.3 to 4.6, and Manganese - 404.5 to 6.7. These results indicate the major trace elements which may be found in the mine spoils as well as those that may be dispersed by coal-fired power plants at Colstrip.

Munshower (1975) studied the range resource in the Colstrip area to determine the effect of stack emissions from coal-fired generating plants. As part of the study, baseline levels of toxic material were determined in herbivores, plant species, and in the soil system to identify possible sites of accumulation. Total biomass production on two rangeland sites averaged 900 lbs/acre. Soil concentrations of iron, manganese and zinc (which are essential micronutrients for plants) were found to be in the normal ranges. Cadmium concentrations in the soil were 0.5 ppm for acid-extracted values and less than 0.1 ppm for DTPA extractions. The plant tissue concentrations in perennial grasses were less than 0.15 ppm for cadmium, and it was 1.0 ppm for nickel, 15 to 40 ppm for zinc and 20 to 60 ppm for manganese. The survey showed that the Colstrip area was a pollutant-free grassland.

D. Summary

The above literature review brings to a sharp focus the significant potential that application of sludge and refuse could have on reclamation of mine spoils in Montana. There is an urgent need for the economic disposal of sludge as well as refuse in Montana. There is also an urgent need for both macro and micronutrients in reclaiming any land which is despoiled by mining. Both needs can be simultaneously met by using the sludge and refuse as soil amendments. The research that needs to be done should quantify the requirements of sludge and garbage, and evaluate the economics in relation to transportation

and commercial fertilizer applications. The literature indicates that the major deleterious effect of trace metals which is not necessarily an insurmountable limitation, can be overcome by informed management.

III. ACCOMPLISHMENTS--PHASE ONE

The work from June 16, 1975 to April 1976 has been described in Progress Report No. 1 dated April 1976 and included herein as Appendix 1. The body of this report is essentially confined to a description of the work accomplished between April and August of 1976.

A. Summary of Progress

The work described in Progress Report No. 1 is summarized as follows:

1. Cooperation has been established with: (a) the City of Great Falls (to save and stockpile sludge and to supply a packer truck for the transportation of municipal refuse), (b) the City of Billings (for samples of sludge for analysis), (c) Rice Trucklines (to contract to transport wastes from Great Falls to Colstrip), (d) Hallett Mineral Company (for lending their 8-ton disc), (e) Peabody Coal Company (for notable cooperation in establishing an experimental site at the Big Sky Mine and lending men and powered equipment), (f) John Prince Transportation (to contract the movement of heavy equipment from Hallett Mineral Company at Vananda to Colstrip), (g) the research team under the direction of Richard Hodder (for advice in greenhouse experiments and for agreement to conduct crop studies at Colstrip), (h) Henningson, Durham & Richardson (for data and analysis of handling costs of municipal refuse), and (i) the Departments of Chemistry and Plant & Soil Science (for advice and assistance in chemical analyses).

2. Plans for installation and monitoring of field experiments were completed.

3. Progress was made in the development of inexpensive lycimeters.

4. Selected chemical tests to characterize City of Billings sludge, City of Great Falls sludge and refuse, topsoil and shale (blue clay) from the experimental site at the Big Sky Mine near Colstrip, and mixtures of sludge and refuse with clay have been made and are presented in the appendix.

5. The first greenhouse experiments with unfertilized topsoil, blue clay, and mixtures of blue clay, refuse, and sludge were made and are reported in the appendix. The results indicate that any of the mixtures of refuse and/or sludge tested resulted in three to five times as much growth as that obtained in topsoil and four to six times as much as that obtained in blue clay. Infiltration rates were greatly improved by the addition of refuse. These results are successful and encouraging.

Between April and August of 1976, the additional accomplishments are summarized as follows:

6. To compare the use of wastes under the worst conditions with the use of topsoil under the best conditions, a second greenhouse experiment was completed. Several different mixtures of unfertilized clay and refuse and/or sludge were tested with heavily fertilized topsoil.

7. A long series of tests and development culminated in the design of a satisfactory and inexpensive lycimeter. Fifteen of these lycimeters, enough for a field installation, were constructed.

8. An inexpensive vacuum collection system to sample the lycimeters was developed and 15 units were constructed. A means for operating the vacuum system in the field has been tested.

9. An experimental site at the Big Sky Mine of Peabody Coal Company near Colstrip was surveyed and the construction staking was completed.

10. A ton of pulverized municipal refuse was transported from Great Falls to Big Sky Mine and successfully plowed into the ground with an 8-ton Towner disc.

11. Funds from other sources were obtained to remodel a Varian AA-5 atomic absorber by installing a Woodriff furnace and attendant electronic controls, strip chart recorder, and variable transformers. The plans were completed, the contract let, and the modifications are now under construction. When completed, it is expected to simplify and hasten the analysis of heavy metals in soils and water.

12. Limited work was done on familiarization and preliminary testing of a new similar atomic absorber equipped with a Woodriff furnace. Exploratory testing with solid samples is in progress during the infrequent times when the instrument is available for our use.

13. Thoroughly mixed and finely pulverized samples of mixtures of soil and refuse were successfully obtained by grinding dried samples overnight in a porcelain ball mill.

14. Two 12-inch diameter columns were constructed for laboratory tests to trace the movement and retention of heavy metals in blue clay from the Big Sky Mine. They will be loaded and the tests will be started as soon as funds are available for the requisite preliminary chemical tests.

These topics are reported more completely in Sections III-B to III-I.

B. Second Greenhouse Experiment

1. Objectives. The objectives of the second greenhouse experiment were: to gain further insight into the effect of different amounts and mixtures of refuse and sludge with clay and to compare a crop yield from sewage or sludge mixtures with the best yield obtainable from fertilized topsoil. The topsoil in these experiments was a select sandy clay relatively rich in humus.

2. Procedures. The procedures were similar to those of the first greenhouse experiment (pp. 64 to 68) except that fertilizer was added only to the pots containing topsoil. A full dose of fertilizer consisted of 30 pounds of NO_3-N/acre, 30 pounds P_2O_5/acre and 30 pounds K_2O/acre. One set of four pots received half the full amount of fertilizer. The full dose was applied in three equal increments at 1, 15, and 30 days after seeding.

The legend given in Table 6 was established to shorten the required terminology in describing various pots.

TABLE 6

LEGEND FOR SOIL-REFUSE-SLUDGE MIXTURES

Symbol	Explanation
T	Topsoil. From a stockpile at Big Sky Mine
C	Clay (shale). From the experimental plot at Big Sky Mine
F	Fertilizer. Full or "standard" dose
1/2 F	Fertilizer. 50% of "standard" dose
TF	Top soil and fertilizer
T 1/2 F	Top soil with 1/2 fertilizer
6R	6" loose refuse mixed with 16" clay
3S	3" wet sludge mixed with 16" clay
3SR	3" wet sludge plus 6" refuse and 16" clay
1-1/2 SR	1-1/2" wet sludge plus 3" refuse and 16" clay

The legend is complete enough so that any symbols not found in Table 6 can be readily interpreted.

3. Results. The results are shown pictorially in Figures 1, 2, 3, 4, 5, and 6, and the growth data and uptake of metals are given in Table 7. The results of the second greenhouse experiment confirm the first experiment because nearly the same results were obtained from both. The growth with topsoil and fertilizer was better than growth with any combination of refuse or sludge.

A. T+F. "Standard" application amount.

B. T+½F. Half of "standard" amount.

Fig. 1. Fertilized Topsoil. Second Greenhouse Experiment.

A. 3R. 3 inches refuse per 16-inch depth.

B. 12R. 12 inches refuse per 16-inch depth.

Fig. 2. Unfertilized Refuse and Clay. Second Greenhouse Experiment.

A. 4S. 4 inches wet sludge per 16-inch depth.

B. 5S. 5 inches wet sludge per 16-inch depth.

Fig. 3. Unfertilized Sludge and Clay. Second Greenhouse Experiment.

A. 1-1/2 SR. 1-1/2 inches sludge + 3 inches refuse per 16-inch depth.

B. 3SR. 3 inches sludge + 6 inches refuse per 16-inch depth

Fig. 4. Unfertilized Mixtures of Sludge and Refuse. Second Greenhouse Experiment.

Fig. 5. Unfertilized Topsoil. Second Greenhouse Experiment.

Fig. 6. Overview of Second Greenhouse Experiment.

TABLE 7

PLANTS IN SECOND GREENHOUSE EXPERIMENT
Fertilizer added only to topsoil

Symbol	Average results from four planting pots								
	T	T+F	T+½F	3R	12R*	4S	5S*	1½SR*	3SR*
Fertile seeds, %	50	51	53	20	28	30	25	30	35
20-day height, cm	3.8	6.4	4.8	6.4	6.4	7.3	5.7	7.9	6.7
40-day weight per pot:									
Wet, g	0.491	5.339	4.103	1.187	2.071	3.654	1.854	2.951	3.814
Dry, g	0.121	1.125	0.834	0.256	0.439	0.697	0.488	0.624	0.650
Moisture, % (dry basis)	305	378	392	363	372	424	280	373	445
Soil P, ppm	16	72	--	29	78	--	--	132	146
Soil NO_3-N, ppm	3	144	--	78	52	--	--	49	38
Metal uptake by crop:									
Zn, ppm	46	72		114		119		132	
Cd	0.16	0.11		0.16		0.27		0.27	
Hg	i	i		i		i		i	
Pb	0.96	1.1		2.0		1.2		0.98	
Cu	6.5	5.5		8.9		9.6		9.8	

"i" indicates insufficient crop for measurement
* second planting in pot used for first experiment

Fertilization at 15 lb/acre of each major constituent (NO_3, P_2O_5, and K_2O) was less than optimum. A comparison of the nutrients seems to indicate that the high growth in T+F (topsoil plus full fertilizer) was apparently due to the large amount of available NO_3-N. The substantial NO_3-N in wastes may have been reduced by bacterial action. The uptake of heavy metals was nearly twice as great in plants rooted in refuse and/or sludge than those rooted in topsoil and fertilizer. However, there is an anomaly in Table 7; crop growth in 4S was better than in 5S. The amounts of grass obtained were insufficient for all chemical analyses and tests for mercury could not be made.

Insofar as plant growth is concerned, fertilized topsoil quite evidently produced better growth than did mixtures of clay and solid waste. On the other hand, mixtures of clay and/or solid waste produced many times as much growth as unfertilized topsoil. However, these results were obtained under optimum conditions of temperature and watering and are not truly indicative of field results. Furthermore, other beneficial effects of refuse, such as improved infiltration capacity and possible resistance to erosion were not measured.

C. Lycimeters

Lycimeters are discussed in the appendix (q.v. p. 63), but it is worthwhile to review some of that material to give continuity to this discussion. Lycimeters are needed at a depth of approximately three feet in order to capture percolating water which might carry some of the heavy metals of interest. A search for adequate lycimeter installations led to those used by Smith (1975a). He developed his lycimeters over a 5- or 6-year period, and they have been fully tested and proven in the field. Essentially, they consist of two hollow "candles" (ceramic tubes about half an inch in diameter) surrounded by pulverized quartz contained in a stainless steel box four feet long, eight

inches wide and six inches high. Each candle is connected to a PVC pipe carefully laid on a self-draining gradient. The candles must always be completely full of water and there is a separate charging system to accomplish this should any air enter the candles. A high vacuum is maintained on the candles which keeps the crushed silica nearly dry at all times, but the microscopic pores are so fine that surface tension prevents the intrusion of air. Any water percolating downward to the lycimeter is intercepted and drawn into the candle from which it flows down the PVC pipe to a central collection station. The system requires a constant vacuum, which must be maintained by a vacuum pump, which in turn requires a source of electrical power.

For the purpose of this project, Smith's system has serious drawbacks: (a) it is relatively delicate and would be completely destroyed by freezing, (b) it is difficult to install properly, and (c) it is expensive. Smith (1975b) estimated the cost of one lycimeter as $4500 ready for installation. The first disadvantage is not serious, the second one is, and the third precludes the Smith lycimeter. Five lycimeters plus the installation would cost more than $20,000. Other lycimeter plans were investigated but without much success. Consequently, the development of an adequate yet inexpensive lycimeter was mandatory.

For the purpose of this research, an adequate lycimeter must possess the following attributes: (a) inexpensive--the total cost of all lycimeters, the collection system, and the installation should not exceed $5,000, (b) they must be easy to install, (c) they should be rugged and able to withstand differential settlement of the soil above and below, (d) because the soils are so impervious, and the amount of percolate is expected to be small, the liquid reservoir within the lycimeter must be a minimum, (e) they must be self-priming because the use of a flushing system to reprime them would be difficult at best

and lose samples at worst, and (f) if practical, they should be immune to freezing.

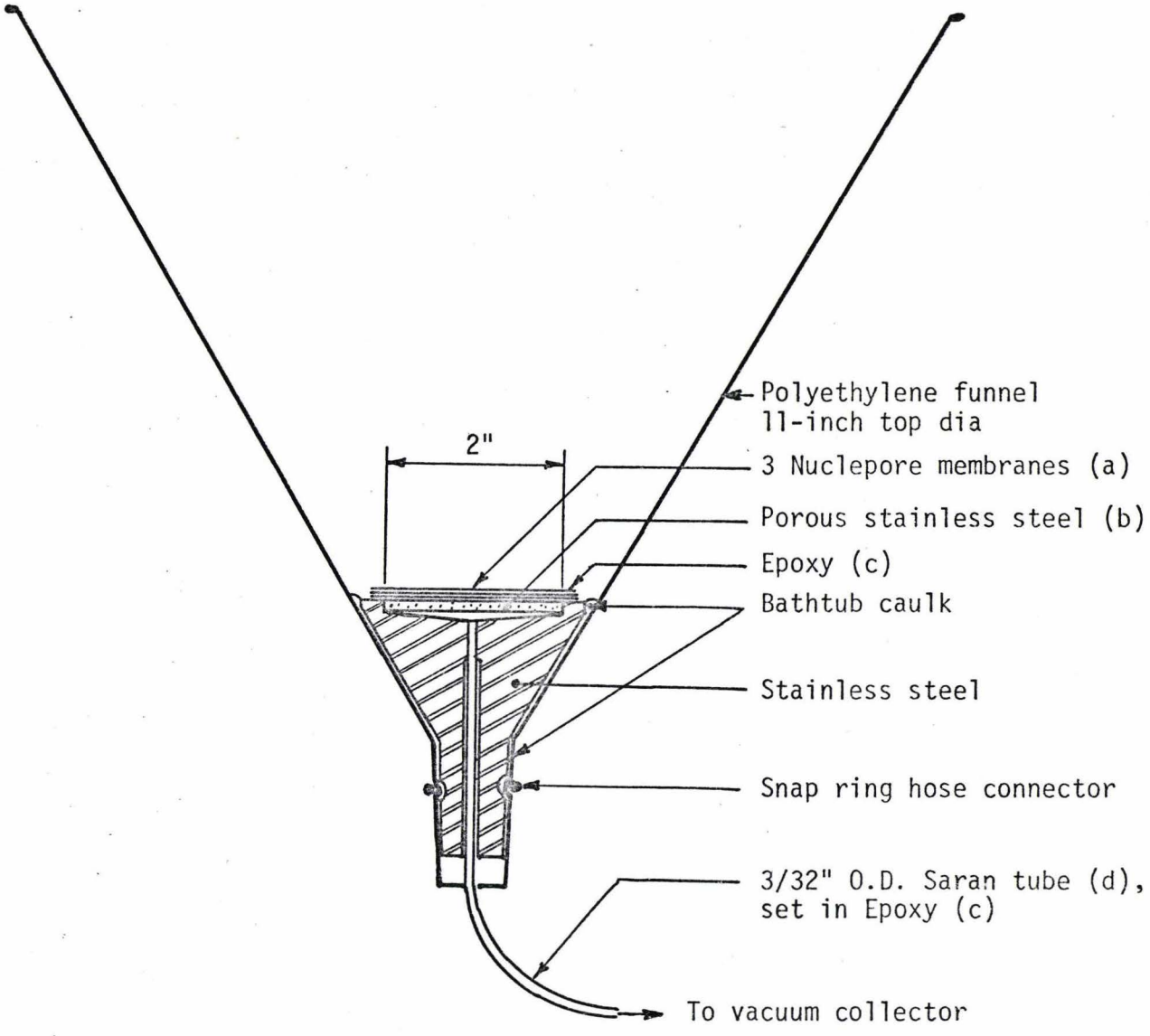
Many designs or modifications were tested until the device shown in Figure 7 was perfected. It meets all of the above objectives except that the saran tubing crumbles upon freezing. This disadvantage can be overcome by using stainless steel tubing (which is expensive) instead of saran, by burying the lycimeters below the frost line, or by keeping a watch upon the frost line, and, when necessary, covering the entire lycimeter installation with straw and/or black plastic. The frost line at Colstrip is not normally deeper than about 18 inches. If intense cold occurs with no snow cover, the frost line could go as deep as three feet, but a watch will be kept, and the lycimeters will be protected if necessary.

Fifteen lycimeters are to be installed in groups of three, with each lycimeter completely independent of the others. Thus, if one fails the two remaining ones can supply the data. These lycimeters have been built and are ready for installation.

Installing them requires digging five trenches four feet deep and approximately 30 feet long plus a central, shored and insulated pit, 6 feet deep, 6 feet wide, and 8 feet long to accommodate the vacuum-collection system. The construction work is to be done by Doeden Construction Company of Forsyth, Montana at an estimated cost of $2250. The cost of the lycimeters and the vacuum-collection system was about $1472, so the cost per lycimeter was $98, and the installed cost is expected to be about $248.

D. Vacuum Collection System

The objectives of the vacuum system were: (a) reliability, (b) economy, (c) independence for each lycimeter, (d) ease of maintenance, and (f) no



Scale: ½" = 1"

(a) N 080 CPR 076 00 membranes with 0.8μ pores
Nuclepore Corp., 7035 Commerce Circle, Pleasanton, CA

(b) 7S PSS D 316, 1/8" thick
Pall Trinity Micro Corporation, Cortland, NY

(c) Gagekote #5
William T. Bean Inc., 18915 Grand River Ave., Detroit, MI

(d) Saran tubing 3/32" OD x 1/64" wall
Soilmoisture Equipment Co., PO Box 30025, Santa Barbara, CA

Fig. 7. Lycimeter

requirement for electrical power. The solution obviously called for a series of fifteen vacuum chambers connected to the saran tubing leading to the lycimeters in such a manner as to permit ready sampling of the effluent. The design in Figure 8 fulfills these objectives. Each bell jar can be evacuated with a 1/12 hp laboratory vacuum pump in about a minute. The vacuum pump is to be powered by an automobile battery and a dc-ac converter.* Laboratory tests indicate the system will hold a vacuum for at least two weeks with no loss. If the vacuum is lost, or if air gets into the system, the entire assembly can be evacuated again and it operates adequately under those circumstances. All fifteen vacuum collectors are complete and ready for installation.

E. Site Survey

The site consists of four plots each 100 feet square separated by lanes 20 feet wide. Plot one is to be covered with topsoil, plot two is to be covered with approximately 80 tons of wet sludge at a thickness of about 3 inches. Plot three is to be covered with 6 inches (loose) of refuse, and plot four is to be covered with 6 inches of refuse and 1-1/2 inches of sludge. The topsoil will be unplowed but the waste on plots 2, 3, and 4 will be incorporated into the upper 16 inches of soil by means of an 8-ton Towner disc.

As there is no chance to gather background data before the experiments with seeding begin, a set of lycimeters in the dividing strip is to be used to monitor the background. The entire area will be fenced to keep vehicles and cattle away. The fence can be electrified by attaching it to a nearby electrified fence.

The site has been staked for the plan shown in Figure 9 and is ready for the contractor to install the lycimeter trenches and the central collection station.

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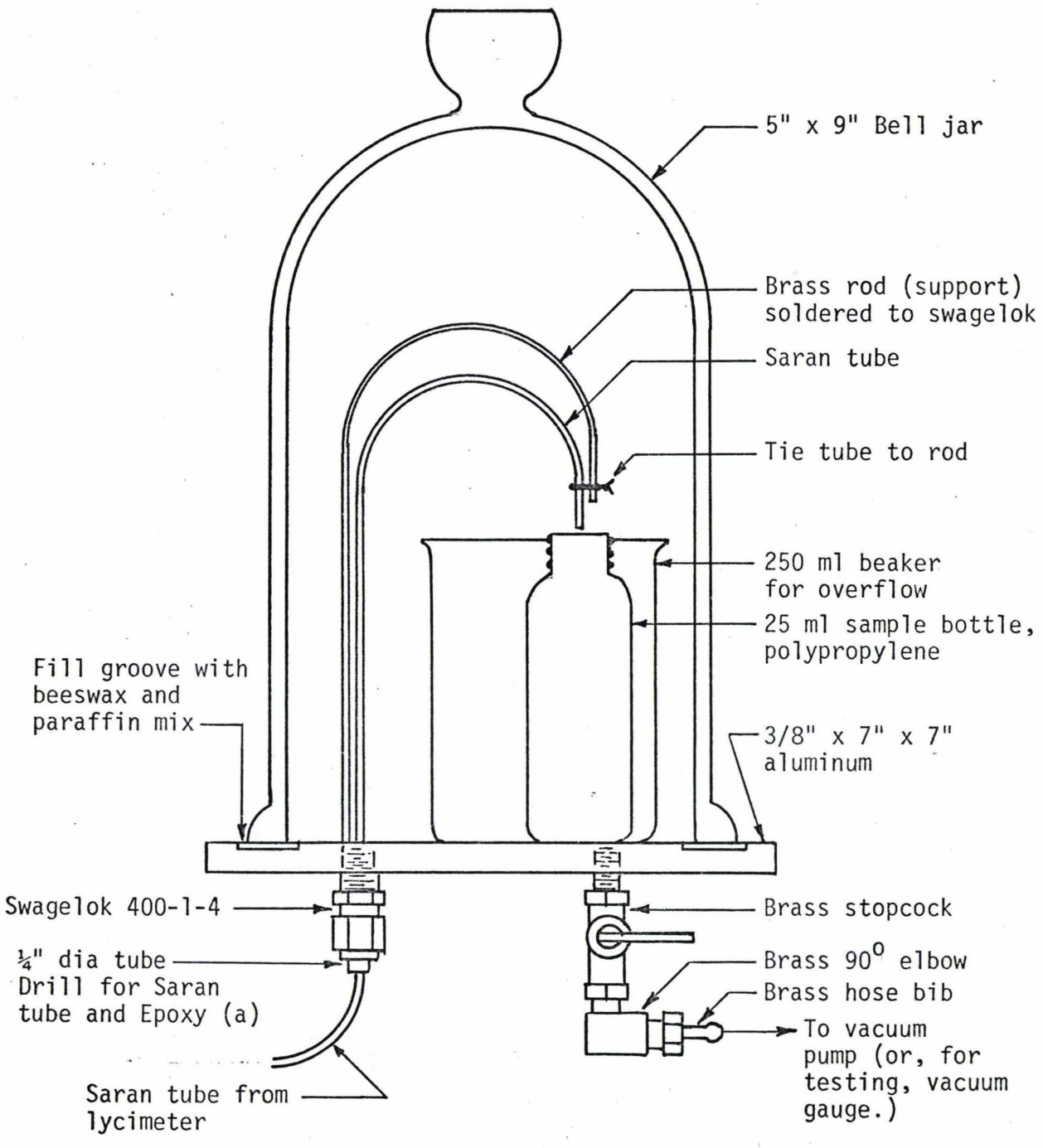
*Powercon Model 12ESW25. Cornell Dubilier Electronics, Fuquay-Varina, NC.


5" x 9" Bell jar
Brass rod (support) soldered to swagelok
Saran tube
Tie tube to rod
250 ml beaker for overflow
25 ml sample bottle, polypropylene
Fill groove with beeswax and paraffin mix
3/8" x 7" x 7" aluminum
Swagelok 400-1-4
¼" dia tube Drill for Saran tube and Epoxy (a)
Saran tube from lycimeter
Brass stopcock
Brass 90° elbow
Brass hose bib
To vacuum pump (or, for testing, vacuum gauge.)

(a) Gagekote No. 5

Fig. 8. Vacuum Collector

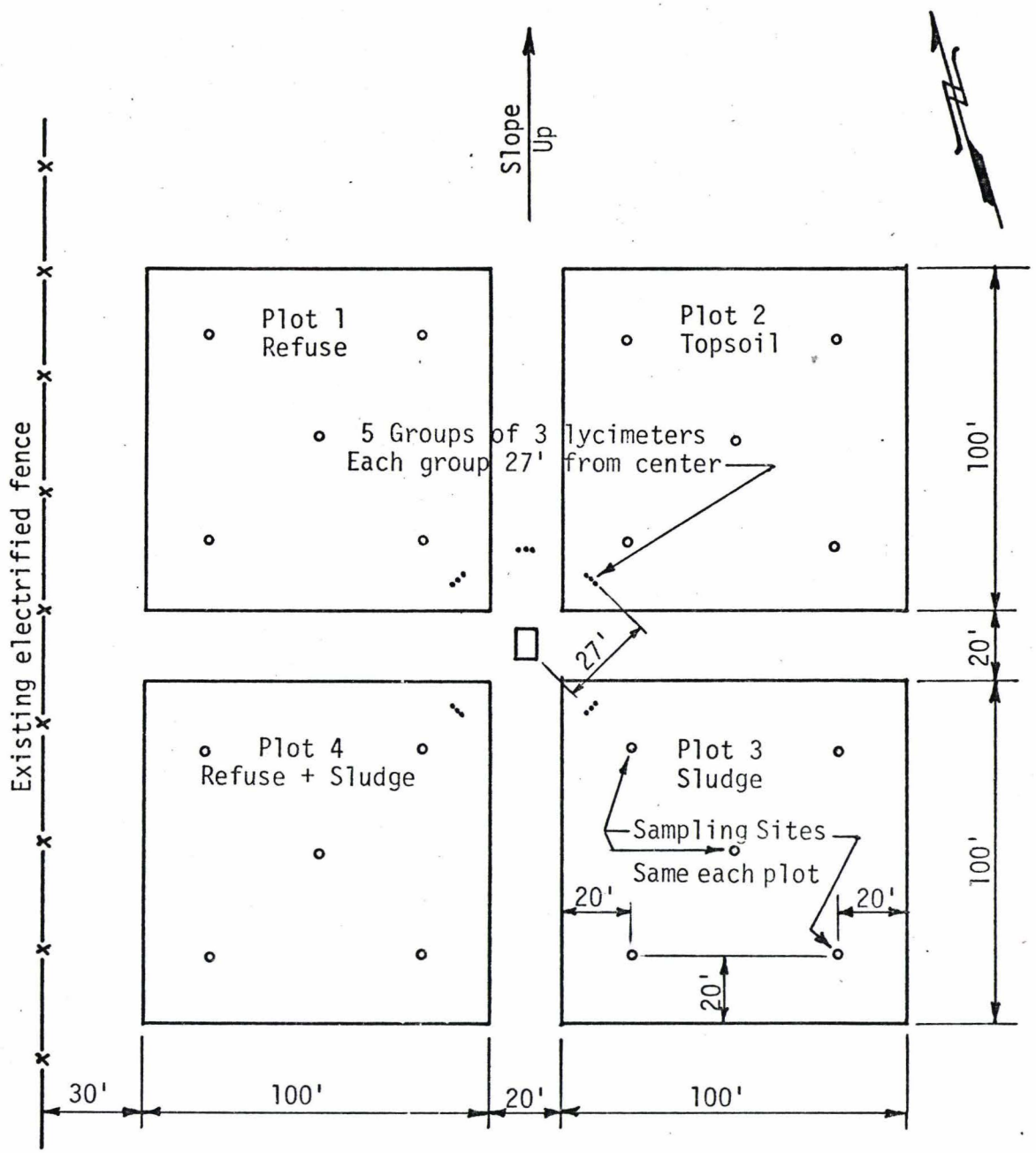


Fig. 9. Experimental Plot on Old Permit Lands. Big Sky Mine, Colstrip

F. Plowing

Incorporation of municipal refuse into the soil was expected to be troublesome. As Figure 10 shows, refuse even after processing by the removal of metallic objects and coarse pulverizing contains large rags, large pieces of plastic, and paper products up to 6 inches square. The refuse tends to pile up on the cutting edges of plows or discs which makes them ineffective. Ordinary farm machinery is useless. Figure 11 shows a farm disc traversing a field of well plowed-in refuse. The disc dragged the refuse out of the ground, quickly became clogged with an excess of refuse, and finally rode over the top, which left piles of loose refuse behind at intermittent intervals. One might speculate that a moldboard plow would also be unworkable. It was thought that a large, heavy disc would be successful and an 8-ton Towner disc with 39 inch diameter, scalloped-edge blades was located at Hallett Minerals Company mine at Vananda, about 65 miles from Colstrip. It was transported to the experimental site at the Big Sky Mine for a test on a ton of refuse obtained from the City of Great Falls.

A plowing experiment was conducted July 7 with the objective of determining whether the big disc would be satisfactory and also to see whether the refuse could be evenly spread. The test was limited to a strip about ten feet wide by 50 feet long, because that was all the refuse that could be hauled by a one-ton truck.

The refuse was spread with rather poor success using a front end loader. Refuse tended to collect on the edge of the loader, so the refuse was not uniformly placed upon the ground. The character of this coarse-pulverized waste appears to make it unlikely that layers much less than six inches in thickness can be spread without special equipment. A motorized grader, or motor "patrol",

Fig. 10. Pulverized Municipal Refuse from City of Great Falls.

Fig. 11. Refuse Piles up in Front of a Small Farm Disc.

with its smooth blade which can be turned at various angles is likely to work much better than the front end loader.

The disc worked well. The scalloped edge of the rotating discs caught the rags and thrust them deep into the soil while the large size and wide spacing of the discs facilitated reasonably good mixing. The tractor was not equipped with hydraulic controls so the hydraulic system of the disc was bled which simply let it collapse, and it was impossible to manipulate the elevation to get the best depth. However, refuse loosely placed to a 4 inch depth was plowed into the soil easily. If the loose depth was 6 inches or more, incorporation was more difficult and required several passes. As Figure 12 shows, some waste is visible at the ground surface, particularly when the depth of refuse is greater than 6 inches. But at depths of 4 inches, the disc, left but little of it visible. Another advantage of this disc is that the blue clay becomes quite finely pulverized and loose, which is ideal for planting.

Winds are strong at Colstrip, but it was evident that the shredded refuse was not subject to movement by wind. Consequently, it should be possible to spread refuse on the surface of the ground and leave it for many days without scattering trash about the countryside.

G. Atomic Absorber

The analysis of heavy metals can be accomplished in many different ways, but in trace quantities the two "best" ways are neutron activation and atomic absorption. Neutron activation is feasible if there are many metals to be analyzed, many samples to be run, and the expensive and sophisticated equipment is available. Atomic absorption is more practical for a small number of metals to be analyzed, and the environmental laboratory at Montana State University is equipped with a Varian Techtron AA-5 atomic absorber.

Fig. 12. After 4 Passes of Towner 8-Ton Disc. Foreground Refuse Was 6 Inches Deep. Background Refuse was 4 Inches Deep.

Metals are ionized in Varian Techtron atomic absorbers by a variety of flames or by a carbon rod atomizer. But flames create a high "noise" level and matrix effects are troublesome. The carbon rod atomizer is more sensitive than a flame, but it is not suitable for all determinations, and the signal is transient. Steady-state conditions are preferable.

Woodriff (1968a, 1968b, 1972, 1973, 1974a, 1974b) has been developing a carbon furnace since 1963. Essentially, the furnace is a thin graphite tube about 10 inches long which can be heated to temperatures between 500°C and 3000°C. The carbon tube is bathed in an inert atmosphere of argon. The proper temperature for the element to be analyzed is selected and the furnace is allowed to reach steady-state temperature conditions. The sample is introduced into a graphite cup about 6 mm in diameter by 9 mm high. If the sample is in liquid state, the cup is dried under an infrared lamp. It is inserted

into a special, hermetically sealed door and lifted into the furnace. The sample is vaporized and nearly steady-state conditions exist for about 1000 milliseconds until the argon sweeps the gases out of the tube. The accuracy and sensitivity of the furnace is better than that of any other type of atomic absorber except the L'vov (1969) furnace (which requires evacuation of the sample chamber and is cumbersome to operate). In contrast, samples can be run at about 2 minute intervals in a Woodriff furnace. Another advantage of the Woodriff furnace is that scores of samples can be prepared by one technician while another operates the furnace.

Ten such furnaces have been constructed and the latest and most advanced in the series is now under construction for the Department of Civil Engineering. For the purpose of this project, an expected advantage of the Woodriff furnace is that dried and finely-ground samples can be charged directly into the graphite cup without intermediate chemical processing. To date, this has not been accomplished, but another group at Montana State University under the direction of Thurston (1976) has within the last few weeks begun experimenting with solid samples of fish tissue in a newly built Woodriff furnace. Analysis of solid soil samples with adsorbed heavy metals has not (as far as is known) been attempted, but the prognosis for success is good and well worth trying. If successful, it will greatly reduce the cost and improve the effectiveness of chemical analyses. It is expected that the furnace will be ready for operation in September of 1976.

No project funds have been or will be used for the Woodriff conversion. The project investigators are gaining familiarity with the Woodriff furnace by utilizing the instrument constructed for Thurston on those infrequent occasions when it is not being used by the Thurston group. It is too early to determine what results can finally be expected, but it is known that the

operation of such sophisticated equipment is scarcely easy or routine. Thus, it can be expected that there will be a lengthy period required for the development of workable techniques.

H. Sample Preparation

The representativeness of small samples of soil or soil-refuse mixtures for the analysis of heavy metals is uncertain because of the variability of the materials both in kind and size. For example, obtaining a 10 gm sample of solid waste which contains large rags, pieces of plastic, paper, leaves, and other materials in macro sizes is difficult, and so is obtaining a small sample of blue clay which contains chunks of shale and coal in various sizes and mixtures. Obviously, large samples can be pulverized and mixed from which smaller samples can be finely ground to produce representative micro samples. Uniformity from sample to sample is expected to be a problem that only the best techniques can solve.

Until the present, the chemical analyses for heavy metals is done by others using chemical extraction to separate heavy metals from the sample. The liquid extracts are analyzed in an atomic absorber equipped with a carbon rod. The cost per analysis is high, and if a way can be found to test a pulverized sample directly (without the necessity for chemical extraction), the work can be greatly reduced. To accomplish this, the first necessity is to obtain a finely-ground thoroughly-mixed sample and one which is not contaminated by the device used for grinding.

A half gallon porcelain ball mill with one inch balls and charged with approximately 100 gm of dried sample was effective in converting a mixture of municipal refuse and blue clay into a material closely resembling cement. All of the particles were extremely fine; none could be identified or differentiated

with respect to another by examination with the naked eye. A 1 mg sample can be expected to be truly representative of the original 100 gm charge.

Eight ball mills were purchased. They can be used either with a borrowed rotating device or a new rotating device can be inexpensively constructed.

Macro shredding can be accomplished with a continuous feed mill borrowed from the Department of Chemical Engineering. Prevention of contamination appears to be the only problem with the use of this mill. Contamination can be reduced by thoroughly cleaning the mill between samples, but that is expensive and time consuming. Tests are to be made to determine the extent to which clean-up is necessary to prevent carry-over of contaminants from one sample to the next.

I. Laboratory Columns

Tracing the movement of heavy metals at the field site is expected to be a difficult task because of the difficulty of control in field installations and also because rainfall (the driving force in the movement of ions) is so sparse. Laboratory tests are desirable adjuncts to field testing because a more controllable set of conditions can be imposed.

The objective of column tests is to correlate the movement of various heavy metals with the movement of soil moisture in the blue clay of the Big Sky Mine. For this purpose two columns of PVC sewer pipe 12 inches in diameter and 6 feet long have been constructed. Preliminary tests are to include application of known amounts of heavy metal salts to soil columns 3, 6, and 12 inches high, after which the 6 foot columns are to be tested with combinations of wastes and additions of heavy metal salts. One column is so constructed that the side can be removed for easy sampling of the soil at any given depth.

IV. CONCLUSIONS

The conclusions are based on laboratory and greenhouse experiments and upon a limited review of the literature. Hence, the conclusions must be regarded as tentative until verified by field experience.

1. Limited chemical analyses indicate that both pulverized solid waste and municipal sewage treatment plant sludges contain plant nutrients such as available nitrogen and phosphorus. The City of Great Falls sludge contained 150 percent of the "allowable" value, but all other concentrations of heavy metals in all materials tested were low and and, hence, satisfactory.

2. Two greenhouse experiments with clay (or shale), select topsoil, and amendments of refuse, sludge, refuse and sludge, and fertilizer showed that, for crop production, any combination of refuse, sludge, or both was more than twice as effective as unfertilized topsoil and more than three times as effective as clay. On the other hand, fertilized topsoil was more effective than any unfertilized combination of refuse and/or sludge in clay, and it seems likely that the increase in growth was due to the greater supply of nitrogen in the nitrate form in fertilized pots. Sludge and refuse contained significant amounts of nitrogen, but the amount that may have become unavailable due to bacterial action is unknown.

3. Amendments of solid waste to clay produced a great increase of infiltration capacity, this might be a primary benefit in making water available to plants by inhibiting runoff, and it might greatly reduce erosion. Other

studies in Colstrip have shown a significant increase in growth due to increases in water-retaining capacity of moisture traps.

4. The literature stated that zinc, cadmium, and copper were the elements that were potentially hazardous in the food chain. Other elements of concern were nickel, boron, lead, and mercury. In Phase One, all of these metals, except boron and nickel, were measured; tin was also measured. In consideration of the exploratory nature of the project and the limitations of funds and manpower, the remainder of the work should be concentrated on zinc, cadmium, and copper; sharply curtailed work should be done on nickel, lead, mercury, and boron; and work with tin should be terminated.

5. Plans were made, contractors were alerted, and sludge is being stockpiled so that: (a) lycimeters can be installed, (b) wastes can be transported to Colstrip and plowed into the ground, and (c) seeding can be completed in the autumn of 1976. These activities are contingent only upon the availability of funds.

6. Inexpensive but satisfactory lycimeters and collection devices were developed, and 15 complete lycimeters and collectors were constructed and are ready for installation. They are to be installed in groups of three at a depth of three feet under five plots: topsoil, clay and refuse, clay and sludge, clay sludge and refuse, and (for control) clay only.

7. The need for inexpensive but sensitive and accurate chemical analyses for heavy metals in soils is expected to be met by modifications (now under construction) to a Varian Techtron Model AA-5 atomic absorber. The modifications consist of a Woodriff carbon furnace with its three transformers, conversion from a single beam to dual split beam instrument, and electronic readouts of peak height and peak area. It is hoped that direct analysis (with no chemical treatment other than oxidizing organic matter by heat) will be possible

by introducing soil samples finely ground in porcelain ball mills directly into the Woodriff furnace. The modified instrument is expected to be operational in September, but it will require several months of testing and development before accurate analyses can be routinely made. No project funds were used for the modifications.

V. ACKNOWLEDGMENTS

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Mr. Ralph Gildroy, Concerted Services, Roundup suggested the reclamation of strip-mined lands in Eastern Montana by amendments of solid wastes. Dr. Takashi Asano assisted in the initial proposal, which was requested by SEAM. Dr. Howard Peavy, Assistant Professor, Montana State University, made the initial arrangements and guided the project in its initial stages. Dr. R. L. Sanks became de facto Project Director in July 1975. Dr. Appiah Amirtharajah joined as Faculty Investigator in June 1976. Mr. David Mosser, graduate student, performed the laboratory and greenhouse work. Heavy metals were analyzed by Mr. Dennis Neuman, Research Associate, Animal and Range Science. Other chemical analyses (e.g., protein) were performed by Mr. Laszlo Torma, Research Associate, Chemistry Station. Some chemical tests were performed by various personnel in the Plant and Soil Science laboratories.

Many people have contributed favors or help--some of it very valuable indeed. Peabody Coal Company contributed manpower, equipment, and an experimental site. Their personnel includes Messers.: Larry Fox, Superintendent; Tracy Hendricks, Assistant Superintendent; and Gene Tuma at Big Sky Mine, and Joe Lake, Director of Operations at Denver. Mr. Irv Sewell of Hallett Mineral Company, Vananda, contributed the 8-ton disc. Mr. Jack Holland, Director of Public

Works, City of Great Falls, obtained official permission and made the arrangements for supplying refuse and sludge. He was assisted by Messrs. LeRoy Lucker, and Dennis Karaffa. Mr. Jerry Underwood, City of Billings, sent us samples of sludge. Drs. Douglas Dollhopf and Frank Munshower and Mr. Richard Hodder, Department of Animal and Range Science, Dr. Hayden Ferguson, Department of Plant and Soil Science, have given advice on crop husbandry and lycimeter installations. Dr. John Amend, Dr. Ray Woodriff, and Mr. Garry Dewalt, Department of Chemistry, are cooperating in improving our atomic absorber.

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APPENDIX

PROGRESS REPORT NO. 1

to

Forestry Sciences Laboratory
Intermountain Forest and Range Experiment Station
USDA Forest Service
Logan, Utah

on

EVALUATION OF SOLID WASTE AS PHYSICAL AND CHEMICAL AMENDMENTS IN REVEGETATION OF COAL SURFACE MINE SPOILS

INT GRANT NO. 22

by

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Professor of Civil Engineering and Engineering Mechanics
Montana State University
Bozeman, Montana

April, 1976

A. PURPOSE

The aim of this project is to evaluate municipal refuse and municipal sewage sludges as soil amendments. Factors to consider include: benefit as a fertilizer and a soil conditioner, the fate of heavy metals, and the economics. The project involves a comparative study of plant growth under various conditions, monitoring the movement of heavy metals (through the soil, in leachate, and through uptake by vegetation), and evaluating the cost of application of sludge and refuse versus the cost of using topsoil as a land reclamation practice.

B. PROGRESS TO APRIL 15, 1976

The work to date consists of five phases: (1) plans for field installations, (2) development of lycimeters, (3) greenhouse tests, (4) development of analytical methods, and (5) evaluation of the work of others.

1. Plans for Field Work. Permission has been obtained from Peabody Coal Company to establish a site on Old Permit lands in Township 1, Range 41E, Sec. 27. The site selected is flat and level. The soil is called blue clay and is actually a broken shale with clods up to many inches in diameter. Four plots 100 ft square will be separated by 20 ft lanes. The four plots can accommodate the following four surface applications: (1) topsoil, (2) 6 in. of refuse, (3) 3 in. of sludge, and (4) the 6 in. of refuse plus 3 in. of sludge. There will be no treatment on the 20 ft separation lanes. To measure heavy metals in leachates, there will be five lycimeter installations (one for each of the four plots plus one for a 20 ft

lane). Each installation will consist of three lycimeters, and all will lead to a central pit with wooden shoring. Because soils and especially garbage and sludge vary so widely, less than three lycimeters per site can not be considered representative.

Rice Truck Lines of Great Falls will haul the refuse and sludge. Doeden Construction Company of Miles City will dig the ditches and install the central pit for the lycimeters. Hallett Minerals will lend a 36-in. disc and Prince Transportation of Forsyth will haul the disc from Hallett Minerals mine to Colstrip. Peabody Coal will lend a bulldozer and operator for spreading the refuse and pulling the disc.

Ten foot square, completely contained, box lycimeters were installed near our site by Colorado State University, and the Animal and Range Science group intends to use them in laboratory experiments in which heavy applications of irrigation water will be applied to determine the movement of heavy metals and nutrients under severe precipitation. The cost wil be minimal and is included in the 1976-7 budget.

Plans have been made to cooperate with the Animal and Range Science group (under the direction of Richard Hodder) to monitor the growth of the plants and to test height, weight, protein content, nutrients, and heavy metal uptake by the plants. The Civil Engineering group will: (a) monitor the fate of heavy metals in soil, (b) utilize the applicable part of the work of Henningson, Durham and Richardson, which is evaluating reuse of refuse for the State of Montana, (c) make an economic evaluation of wastes for soil amendments, (d) compare the costs with those for the use of topsoil, and (e) will assume overall responsibility for the project.

2. Development of lycimeters. Early in the project, it became apparent that the most serious problem associated with the use of municipal refuse and municipal sludge was the fate of heavy metals. Heavy metals are often toxic and cumulative. There is serious concern about such metals finding their way into underground aquifers and contaminating water supplies. Furthermore, vegetation may adsorb excess amounts of heavy metals which could be transferred to man via meat products. On the other hand, the heavy clays of the eastern Montana region are very adsorptive and would tend to sequester heavy metals. The low rainfall in this region would also be advantageous. But under some circumstances the heavy metals might become a problem. It is important, therefore, to be able to trace the movement of heavy metals. To accomplish this, lycimeters are needed to monitor the leachates, and many soil borings must be made to measure the location of heavy metals adsorbed onto soil particles.

Dr. Richard Smith, Colorado State University, has developed excellent lycimeters over the last decade, and these are now being used effectively in experiments in Colorado to measure the movement of heavy metals and other substances in soils to which municipal sludges are applied. The cost of his lycimeter is about $4500 per installation and since five installations are needed at Colstrip, such a cost is prohibitive.

Considerable effort has been directed at the development of a satisfactory lycimeter which would be both cheap and effective. Several models have been developed and tested. One of the latest in the series consists of a ten inch diameter plastic funnel with a stainless steel receptacle at

the transition between funnel and stem. The receptacle is machined so that a porous disc of sintered stainless steel can be used as a support for a Nuclepore polyvinylchloride filter containing sub-micron holes. Tests beginning early in March were only partly successful and inconclusive, but the unit may not be rugged enough for field use. Tests are beginning with a glass filter funnel into which a fritted glass disc is welded at the top of the stem. Such lycimeters have been used, although not in the form we require. Such a lycimeter is probably sufficiently rugged if protected from freezing. They will be buried three feet deep. Last year during the worst of cold weather, frost did not penetrate more than 18 in. at Colstrip, but the weather will be monitored and if it is unexpectedly severe, the lycimeters will be protected with straw.

If a decision is made to use the glass lycimeter, the project will be delayed two months because the fritted glass discs are manufactured only on special order and the delay is eight weeks after receipt of order.

3. Greenhouse tests. Tests of (a) blue clay, (b) topsoil, (c) blue clay mixed with various amounts of sludge, (d) municipal refuse, and (e) mixtures of sludge and refuse were studied in a greenhouse test of 40 days duration. No fertilizers were used. (A second greenhouse experiment is now underway in which fertilizers are added to clay and topsoil.) Table 8 shows a chemical analysis of the soils. As shown by Table 9 and Figures 13 and 14 the growth in a mixture of sludge, waste, and clay is dramatically better than growth in topsoil. All combinations of clay and refuse, sludge, or a combination of sludge and refuse were about the same and far better than

TABLE 8

CHEMICAL ANALYSES OF SOILS AND AMENDMENTS

Material	Clay	Top Soil	Billings Sludge	Great Falls		Clay plus Great Falls Amendments					
				Refuse	Sludge	8:3R	8:6R	5:1S	3:1S	32:12R:3S	16:12R:3S
Symbol	C	TS	BS	R	S	6R	12R	3S	5S	1.5SR	3SR
Constituent											
Nutrients											
Total N, ppm	2800	600	26400	10700	18800						
Total P, ppm	6680	8030	5240	480	9160						
Plant-available nutrients											
NO_3-N, ppm						46	>74	24	32	>74	>74
PO_4-P, ppm						37	85	>246	>246	209	239
Heavy Metals											
Zn, ppm	6.0	2.0	1462	118	3021						
Cd, ppm	0.12	0.06	7	5	17						
Hg, ppm	0.033	0.015	0.9	∿2.5	1.4						
Pb, ppm	4.2	1.1	182	327	289						
Cu, ppm	4.0	0.6	375	120	575						
Sn, ppm	0.2	0.2	<2.5	<1	<2.5						

TABLE 9

PLANTS IN FIRST GREENHOUSE EXPERIMENT
No fertilizer used

Symbol	Average results from four planting pots							
	C	TS	6R	12R	3S	5S	1.5SR	3SR
Fertile seeds, %	50	54	46	44	50	48	33	40
20 day height, cm	4.7	6.4	6.4	8.3	5.0	7.3	8.6	7.9
40-day weight,								
wet, g	0.414	0.539	3.045	2.976	2.942	3.204	2.192	2.657
dry, g	0.093	0.122	0.537	0.526	0.506	0.550	0.389	0.465
Moisture, %(dry basis)	345	342	467	466	481	483	463	471
Protein, %(dry basis)	24.2	23.1	29.4		30.1		28.8	
Heavy metal uptake								
Zn, ppm	126.9	62.6	133.0		156.0		161.6	
Cd, ppm	i	i	0.18		0.23		0.24	
Hg, ppm	i	i	0.21		0.20		0.21	
Pb, ppm	i	i	2.16		2.18		2.53	
Cu, ppm	21.4	16.7	21.1		25.4		26.7	

i indicates insufficient sample for analysis.

Fig. 13. Growth at 40 Days in Topsoil

Fig. 14. Growth at 40 Days in Clay-Refuse-Sludge Mix (3SR)

topsoil. Furthermore, the refuse appears to improve the "wick" action of the soil so that infiltration is remarkably better.

4. Analytical methods. All chemical tests have been performed by the Departments of Plant and Soil Science, Animal and Range Science, or Chemistry because it is the most economical way to perform only a few tests. But in the future a great many tests must be performed and the cost for such tests would be prohibitive. Work with Dr. Ray Woodriff on a quick method for monitoring heavy metals in soils and in water shows considerable promise and if it becomes successful would greatly reduce costs and laboratory time. The method consists of: (a) fine grinding the soils in a porcelain ball mill, (b) inserting a few micrograms into a tiny graphite cup, and (c) sealing the graphite cup and inserting it into a carbon tube furnace in an atomic absorber. The high temperature vaporizes the metals which pass through the graphite cup without interference. Water samples are deposited in the graphite cup which is dried under an infrared lamp. How well the system will work with the high organic content produced from the sludges is yet to be determined. If the organics do not interfere, the time per test can be greatly reduced. If the organics do interfere, an extraction method will be necessary.

The Department of Civil Engineering possesses an excellent atomic adsorber and has a Woodriff carbon tube furnace on requisition. The installation of this apparatus will cost the project nothing. However, funds for capital equipment have not yet been released.

5. Evaluation of the literature. Some literature has been collected and part of it studied. The work of Henningson, Durham, and Richardson (State of Montana Solid Waste Management and Resource Recovery Study) on transportation costs should be useful. The Fulton County Sludge Disposal site for the Metropolitan Sewage District of Greater Chicago was visited and discussions were held with Professor Tom Hinesly and Dr. Cecil Lue-Hing, Director of Research and Development. Henry C. Hyde, East Bay Municipal Utility District, Oakland, is evaluating the application of municipal sludge to land. George D. Ward, consulting engineer, Portland, Oregon, has agreed to hold a seminar at Bozeman on municipal waste reclamation projects around the world.

C. EXPECTED ACCOMPLISHMENTS WITH PROJECT FUNDS

Work which can be accomplished by June 30, 1976 with available project funds includes the following.

(1) Complete the second greenhouse test, make the chemical analyses, and evaluate the results.

(2) Test a King soil sampler at Colstrip and determine whether it will be a satisfactory soil sampling device. Test soil probes for determining zones of saturation. (If necessary, develop or test other sampling devices, although there is no assurance this could be completed by June 30.)

(3) Begin soil preparation experiments, "spike" soil samples with known amounts of selected heavy metals, and make chemical analyses in a Woodriff furnace. Determine whether soil organics interfere.

(4) Construct and test a glass lycimeter with a fritted glass septum.

(5) Survey the site and lay out the lycimeter installation.

The following tests can be completed with the available project funds but probably not within the project period.

(1) Build the lycimeters

(2) Install the lycimeters, the central collection pit, and the fence.

D. PROPOSED EXTENSION OF TIME

A decision (still pending) to use glass lycimeters and fritted discs would delay construction of lycimeters by more than two months because the discs, made only on special order, require at least eight weeks to manufacture after receipt of order. As a wrong decision might endanger the entire project, it is desirable to maintain flexibility and extend the completion date to August 31 for 1975-6 funds without in any way affecting the starting date (July 1, 1976) of 1977-8 funds.

E. AVAILABLE FUNDS

If additional funds become available, the test plowing experiments can be completed and the seminar can be held. If no additional funds are obtained, these two functions must be postponed for 1977-8 funding. Extra funds for test plowing would be desirable at this time. Plowing refuse into the ground is difficult. It might be done with a turnover plow or with a 36-in. disc. Trials at Great Falls with small discs were unsuccessful. Part of the success of the project depends upon obtaining an intimate mix of refuse and soil. It would be best to carry out such tests without delay.

The consequences of failure to plow the municipal refuse into the ground at Colstrip are severe. Colstrip is dry and windy. It will take at least two days to haul the necessary amount of solid waste and sludge to the site. A 36-in. disc is available for only one day at a time, and if the various contractors do not mesh their activities, or if the disc is not effective, it may be impossible to get the intimate mixture of soil, sludge, and refuse necessary. Resorting to makeshift methods (such as the use of scrapers to cover the solid waste) at the last minute may be impractical. Consequently, there must be no doubt the methods selected will work at the chosen site. Otherwise, the costly transportation of refuse will have been for naught and the project might be faced with further liability for cleaning up the area. Depending upon the test conditions and results, it may be satisfactory to make a plowing test at Hallett Minerals (for an approximate cost of $460) or at Colstrip near the site of the test plot for which the approximate cost would be about $725 for hauling a truckload of municipal refuse and for hauling the disc from the Hallett Mine to Colstrip and return.

If funds were available, it would be desirable to have George D. Ward present a one day seminar at Bozeman. The cost would be approximately $500 for travel, expenses, and consulting fee. Ward's expertise has been described.

F. TENTATIVE BUDGET JULY 1, 1976-JUNE 30, 1977

Estimating a budget for 1976-77 is fraught with many more problems than the usual research project. First, much of it is field work in which

dependence upon contractors, weather, and field conditions increase the uncertainties. Furthermore, half of the research is the fate of heavy metals. They might not move at all which would make this part of the project easier and reduce the cost. On the other hand, they might move unexpectedly or rapidly, which would require more sampling trips and tests than anticipated with consequently greater costs. It has been assumed that three lycimeters per plot are sufficient and that three test borings per plot per sample trip are sufficient. But this sufficiency cannot be truly judged until the soil amendments have been placed and chemical analyses can be interpreted to see whether the variations in results are large or small. If large, a statistically greater number of tests must be made to obtain valid results. Three test borings per plot per trip is certainly an absolute minimum and might be considered unsafe. These uncertainties make it unthinkable to couple the minimum in test borings, number of chemical analyses, preparation and testing time, with the maximum in equipment reliability and laboratory effectiveness. Estimates so based would guarantee failure of the project. The surveillance must at all times be adequate to insure that the movement of heavy metals has not escaped the network of lycimeters and soil borings. And as a boring once made can not be repeated, dependence can only be placed upon a satisfactory statistical average. The budget proposed is based upon a reasonable, minimum number of samples and this should be kept in mind as the budget is studied.

The budget is based upon the cooperative, but separate operation of two teams. The Animal and Range Science team under Hodder will plant the vegetation and monitor it. The Civil Engineering group will supervise all

installations, and monitor the soil, the small lycimeters at the plot site, and the "Colorado State University" lycimeters near the plot site. The latter group will also carry out some selected laboratory investigations of the movement of heavy ions in small soil columns.

G. CONCLUSIONS

1. In the greenhouse, where the root zones were kept continually moist, all clay mixtures of municipal refuse, digested sewage treatment plant sludge and combinations of refuse and sludge produced three to four times as much growth on a dry weight basis as did the unfertilized topsoil and four to six times as much growth as unfertilized clay. Plants grown in sludge, refuse or combinations contained 30 to 40 percent more water than did plants grown in either topsoil or clay. With sufficient water, refuse and sludge amendments to clay provide better growth than does topsoil.

2. In greenhouse experiments still in progress, growth conditions in fertilized topsoil are equal to those of mixtures of refuse and sludge amendments and somewhat better than those for sludge alone or refuse alone. However, clay with refuse accepts water more quickly and hence would be more resistant to erosion.

3. The greenhouse experiments did not provide enough growth for definitive analyses of the uptake of heavy metals. The incomplete data appear to indicate that the uptake by plants of heavy metals increases somewhat as the concentration of the metal in the soil increases.

4. The evidence obtained to date indicates clay enriched with municipal refuse and/or sewage treatment plant sludge is superior to the use of topsoil.

5. Tried and proven lycimeters for measuring leachates that might transport heavy metals are prohibitively expensive. Experiments with inexpensive lycimeters are continuing because a completely satisfactory substitute has not been found. Modifications of existing designs coupled with suitable, although perhaps troublesome, field operations are expected to provide a satisfactory substitute for the expensive model.

6. Funds remaining in the project are sufficient for installation of the lycimeters, but they are not sufficient for definitive experiments for applying and mixing the refuse and sludge successfully. Depending upon which lycimeter is selected, the time available to June 31 may be insufficient to install the lycimeters. To guard against these contingencies and to ensure successful installation and operation, the existing contract period should be extended to August 31. However, with good fortune it may still be possible to complete the lycimeter installation and the other scheduled tasks by June 31. No extension of time should be permitted to affect the dates of the 1976-7 budget period, because such extension might not be used.

7. Project funds are insufficient for ensuring the successful application of refuse and sludge to the land or to finance a seminar by an authority on refuse disposal. Plowing experiments (with a disc) will cost about $460 if carried on at Hallett Minerals Mine north of Colstrip, or

$725 if it is necessary to move the disc to Colstrip. A seminar would cost $500. If these funds are not added to the 1975-6 budget, they should be added to the 1976-7 budget.